DOE Renewable Energy Grid Integration
Distributed PV Study Plan
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Background

Due to accelerated cost reductions and associated growth in production, renewable energy technologies such as solar photovoltaics (PV) and wind are expected to grow rapidly during the next couple of decades. As these technologies mature they have the potential to provide a significant share of our nation's electricity demand. However, as their market share grows, concern about potential impacts on the stability and operation of the electricity grid may create barriers to their future expansion.

The DOE is launching a set of studies to examine the potential to overcome these barriers and to define a research agenda that will meet these needs. This set of studies will address both the technical and analytical challenges that need to be tackled in order to enable high penetration levels of solar, wind and other renewable energy technologies. By examining how renewable technologies can be combined with storage, controls and other appropriate technologies, DOE expects to build the foundation for realizing a high penetration renewable energy future while enhancing the operation of the electricity grid. In addition, by directly engaging utilities and other stakeholders in this process, DOE expects to build the confidence of regulators and utilities with respect to maximizing the use of renewable energy technologies.

Integrating renewable energy into the grid consist of two distinct elements, centralized generation and distributed generation. Each of these elements will have different timing and implementation pathways. The centralized generation element will likely be initiated with large wind generation grid integration solutions, followed by Concentrated Solar Power and Hydrogen. The distributed generation element will likely start with solar photovoltaic (PV) implementation, followed by distributed wind and other technologies at the distribution level (<15kV).

A critical goal of carrying out the set of studies, described below, will be to help DOE define a research agenda that will enable it to work with utilities and industry to facilitate the widespread market penetration of renewable energy technologies, including storage systems, advanced power electronics, and controls into the U.S. electricity grid. Control systems are likely to include improved and innovative ways to manage power demand. The studies will also strive to understand the potential impacts on the electricity grid and optimize systems based on benefits to both customers and utilities. DOE expects to work closely with State Public Utility Commissions, utilities, and private sector stakeholders to couple advanced technology development, demonstration and validation projects to enable and promote energy efficient, sustainable cities and communities of the future.

Key issues related to renewable energy grid integration that need to be addressed include:

- Utilizing prototype testbeds and field deployments to evaluate key characteristics of new renewable energy systems and other distributed technologies that maximize grid value.
- Conducting detailed analysis of system performance and grid effects through electrical transmission and distribution (T&D) system modeling and simulation.
- Developing and validating best practices and software tools to facilitate T&D system planning and operation for grid modernization, which includes greater deployment of renewable energy systems.
- Establishing grid infrastructure for localized energy networks (microgrids) including utility load/production control methodologies.
- Establishing grid infrastructure requirements for wide-area control of distributed renewable energy systems integrated into the electrical power system.
- Improving stand-alone capabilities of distributed technologies with storage to improve grid reliability and serve other customer values in terms of enhanced power quality and back-up power functions.
- Validating remote monitoring and dispatch control platforms that integrate with utility control and price signal interfaces to optimize renewable energy and storage system benefits in concert with advanced grid technologies and demand response resource procurement efforts.
- Developing a comprehensive demonstration plan to ensure successful simulation, demonstration, and validation with utilities and industry stakeholders.

Distributed PV Study Plan

This document describes a set of studies that will define the scope and justification of R&D activities that need to be carried out to transform U.S. electricity markets in order to enable widespread adoption of distributed photovoltaics (PV).

By September 2007, these studies will provide a detailed assessment of the economic and technical potential of distributed PV as an element of U.S. electricity markets, and a justification for R&D activities designed to help realize this potential. The studies will also provide a detailed R&D plan for distributed PV, including technology development, testing, and market demonstration activities. This R&D plan will build on related activities that are in-line with broader grid modernization efforts.

Study Area Descriptions

Study Area 1: Advanced Grid Planning and Operation

Guiding Question: "What grid modernization strategies are needed to incorporate mass-deployed distributed PV, and what will be the overall system reliability impacts?"
Subordinate Questions:

- *What are the grid-reliability-driven boundary conditions for maximum possible PV resources installed in a given utility distribution service area? At what point does PV penetration have an effect on grid reliability indices? How can these boundary conditions be modified by inclusion of storage and/or other demand-response technologies?*

- *How will increased PV penetration impact the safety, reliability, security, sustainability, and cost effectiveness (i.e., surety) of the transmission and distribution system?*
- *What are the engineering and physical changes required for transmission and distribution systems to be able to accommodate high levels of PV penetration?*
- *How does distributed PV fit within the larger context of grid modernization?*

Study Description:

This study will develop a plan to understand the grid-reliability-driven boundary conditions related to maximizing the penetration of distributed PV installed in a given utility distribution service area. It will identify the types of electrical system upgrades that are needed to accommodate large penetrations of PV on the distribution feeder, identify the maximum amount of PV that can be added to distribution feeders before upgrades are necessary, evaluate how large amounts of PV operate on a circuit under steady-state and transient conditions, and examine how/if increased penetration of PV in distribution systems cause desensitization of protective relays.

The Study will accomplish the following objectives:

- Define what studies are used by utilities to determine operating stability of the electric power system.
- Define models that will be used (consistent with utility studies) to evaluate steady-state and transient conditions for PV penetration studies.
- Define what data parameters need to be collected on field tests and demonstration system to provide input to the modeling and analysis work in this area.
- Define needed case studies to provide realistic operations of large-scale PV deployment.
- Determine what tools and data are needed to identify optimal locations for siting PV in the distribution system.

<u>Study Area 2: Distributed PV Systems Design & Technology Requirements</u>

Guiding Question: "What might the distributed generation PV systems of the future look like, and what technology development pathways do we need to pursue to enable them?"

Study Description:

This study will generate a set of optimized conceptual system designs that integrate PV, storage, and control technologies for residential and commercial market applications. In addition, this study will identify technology gaps and research and development needs. The study will evaluate the feasibility of using time- and location-specific marginal costs of generation (real-time energy costs), distribution (real-time demand costs), and customer/utility requirements in an optimization routine to configure systems to maximize PV system value. The study will evaluate a range of approaches for assigning functional requirements to various elements of a PV system, including modules, inverters/charge controllers, batteries and other forms of storage (thermal storage in the form of hot water, ice storage systems, etc.), main bus panels, and building energy management systems (EMS's).

The study will evaluate system-level requirements and associated performance/cost specifications for component technologies based on the following considerations:

- Building types and representative load profiles (energy and demand).
- Geographic location.
- Electrical storage system capacity ranges.
- PV/Storage system operational strategies.
- Back-up power requirements (at various levels: minutes, hours, days).
- Power conversion system requirements, for example, active and reactive power compensation and voltage and frequency regulation (stand-alone mode); coordination of multiple renewable and storage systems; reliability requirements to ensure reliable power, including withstanding surges from lighting or the grid; limits on reverse power flow at a substation feeder breaker.
- Data requirements, including real-time energy and demand pricing, and data needed to anticipate future (next day) solar generation and site/utility demand.

In addition this study will identify the engineering and physical challenges to transmission and distribution system design that will be required to accommodate high penetration levels of distribute PV systems. For example, the study will:

- Examine the types of sensors and secure communication links, including software and hardware, best-suited for utility-interactive control of site-based distributed generation, storage, and load management systems.
- Identify safe techniques for energizing the distribution system with PV/storage during outages, such as establishment of microgrids.
- Evaluate the impact of high speed controls that can adapt to the distribution system conditions in real-time in order to raise the system's resistance to cyber attacks.
- Assess the relevant trends in smart metering and related utility rate structures and electricity prices.

The study deliverables will include:

- An assessment of the state of the art with respect to advance system designs.
- A summary of ongoing related research activities, i.e. for PV and other DG technologies.
- Flow-down of requirements from market requirements/market signals, to system-level operational strategies, to component-level performance/cost specifications.
- Functional block diagrams of system configurations for both residential and commercial DG applications.
- Initial cost assessment of storage and control options, including operation, maintenance, and lifetime relative to duty cycles and depth of discharge.
- Identification of product vendors currently supplying needed components and system installations.
- "Gap analysis" of targeted performance/cost specifications versus equivalent parameters for technologies that are presently commercially available.
- Identification of technology development/research needs arising from gaps.

<u>Study Area 3: Field Test & Demonstration Program Definition</u>

Guiding Question: "What field test and demonstration activities are required to evaluate the system-wide and local-distribution network impacts of high concentrations of PV both with and without storage/controls?"

Study Description:

This study will provide information needed to support program planning for field testing and demonstration of distributed energy storage and controls working synergistically with building-based PV installations. It is expected that the plan for these field tests and demonstrations will incorporate plans to acquire both technical data as well as financial performance data gathered from utility and customer accounting systems. It is expected that the resulting field testing and demonstration program will incorporate involvement of other state government organizations, including the California Public Utilities Commission (CPUC) and the California Energy Commission (CEC), as well as major investor-owned utilities and product vendors. The study will outline potential field test and demonstration program elements for PV with and without energy storage systems/controls. The study will include:

- Identification of the full range of partners needed to make a field test and demonstration effort successful, including safety, environmental, codes, controls, etc.
- Definition of the types of field tests and demonstrations needed, including appropriate objectives for demonstration of value on both the utility/wholesale and customer side.
- Descriptions of field tests and demonstrations, including: desired building types and representative load profiles, geographic distribution, storage system capacity ranges, PV/Storage system operational strategies, back-up power requirements, communications and controls capabilities, etc.
- An outline of analysis/demonstration activities required prior to the implementation of field test or demonstration projects.

The deliverables will be a comprehensive review of the field tests done to date, along with a detailed description of the elements that should be included in a successful field-test and demonstration program.

<u>Study Area 4: Customer & Utility/Wholesale Value Proposition</u>

Guiding Question: "What is the value to utilities/wholesalers/load serving entities (LSEs) and customers for various grid architectures and business models?"

Subordinate Questions:

- *For grid architectures with large-scale deployment of distributed PV:*
    - *What is the value to the utility?*
    - *What is the impact on IOU operating costs/economics?*
    - *What is the value of distributed solar to the ISO/RTO?*
    - *What is the value to the customer?*
- *How are grid operations (in terms of unit commitment, capacity requirements, T&D losses, etc.) affected by various levels of PV and what is the affect on the operation of other generation technologies?*
- *How is the environmental performance of the grid influenced by various levels of PV?*

- *How much flexibility and value can demand response capabilities and storage deliver to the grid to facilitate greater use of PV?*
- *How can storage packaged with PV be optimized to provide maximum flexibility and value to the grid?*
- *What types of solar resource data (forecasting and historical) are needed by utilities and customers?*
- *What sorts of business models are possible?*
    - *For IOU selling electricity to residential customers under a PPA for on-site installations?*
    - *For customer-owned PV systems, use of control systems for "active participation" in energy markets via arbitrage opportunities, etc.?*
    - *How can PV be integrated into the Load Serving Entity's business model?*

Study Descriptions:

Value Analysis: This study will provide information needed to assess the value on the utility/wholesale side and customer side for various PV system configurations, grid architectures, ownership/business models, and operational strategies. The study will review the existing literature on the value of PV (both with and without storage/controls), summarize the lessons learned from this literature/experience, and identify specific studies/field tests that need to be completed to fill in the gaps in knowledge. As part of this study a simple tool (either based on spreadsheets, existing tools such as QuickQuotes, or some combination thereof) will be developed. This tool will be used to conduct preliminary sensitivity analyses around each of the key parameters identified in the literature review. The study will accomplish the following objectives:

- Construct a comprehensive dataset using market clearing prices, congestion charges, installed capacity values, etc., to understand the marginal cost of energy at the distribution level.
- Identify and Quantify the various potential benefits including: avoided generation costs, avoided transmission and distribution costs, avoided generation and T&D losses, capacity increase/peak load reduction, voltage/VAR support, phase balancing, harmonic correction, backup power/ power outage mitigation, equipment upgrade deferral, distribution equipment reliability improvements, hedge against volatile fossil fuel prices, rapid and easy PV deployment, environmental and health benefits, avoided water use, job creation etc. This study will quantify the actual monetary ranges (in $/W or cents per kWh) for these benefits where possible.

Production Cost Modeling for Solar Grid Flexibility: This study will lay out a plan to evaluate the large scale interaction of solar electricity technologies with the existing and possible future grid. Based on the actual operation of the electric power system, techniques will be developed for determining the displaced generation capacity, fuel saved, and emissions avoided by deploying varying levels of solar electric generation. While there are a variety of approaches to performing these estimates, the most powerful is the use of integrated "production cost" or "unit commitment and dispatch" models. These models are used by regional grid operators and/or utilities to simulate the performance of their systems, considering the actual dispatch costs, and technical constraints imposed by transmission limits and physical operating characteristics of each power plant in a utilities' system. By utilizing the tools that utilities and regional grid operators employ in their own planning processes this type of analysis will be able to produce results of that are convincing to both regulators as well as utilities/system planners. The study will accomplish the following objectives:

- Define strategies for using a production cost model, such as Prosym, to evaluate the impacts of deploying a variety of solar technologies from distributed solar photovoltaics to utility scale concentrating solar generation.
- Perform preliminary simulations of current and potential future electric power systems. These case studies will be carried out for specific utility systems in the Southwest, Central and Eastern U.S., and will be based on data from existing utilities. Potential partners include: SCE and APS in the Southwest, Xcel in the Central region, and AEP and Duke in the East. The specific cases will be selected based on the set of attributes that characterize a given utility system, so that the range of case studies covers a representative sample of grid architectures, utility/wholesaler cost structures and business models, and demand/load/pricing/rate structures.
- Work with specific utility partners to gather data on system loads, and generator characteristics.
- Evaluate the feasibility of linking to a separate air quality model in order to be able to estimate local air quality benefits.

Resource Assessment for Grid-Integration: This study will evaluate the current state of the art with respect to solar resource characterization and data availability. It will engage a range of stakeholders – utilities, data providers from other areas (such as True Wind), system integrators, NOAA, etc. – to develop a vision of how resource assessment measurement technology, data, and analysis methods, can be advanced to support grid-integration. This study will achieve the following objectives:

- Identify desired improvements to measurement technology, solar irradiance models and data sets, and develop a plan for implementing these improvements.
- Evaluate the need for higher resolution spatial coverage (integrate Perez solar data sets with meteorological data sets for complete U.S. coverage).
- Evaluate the need for higher time resolution data sets (15 minute, 1 minute and 1 second data sets).
- Evaluate the feasibility of solar forecasting (ability to forecast solar data anywhere in the U.S. on a day ahead, 5 minute ahead, or some other basis).

Business Models Definition: This study will develop a variety of business models for the ownership and operation of PV alone and combined with storage systems /controls in the residential and commercial sectors. The system could be owned in whole or in part by the utility, the end-user, or a third party. The resulting operational strategy and benefits accrued may differ based on who owns the system. Also, some parties may wish to influence the operation of the system even if it is owned by a different party. For example, the utility may wish to be able to take control of an energy storage system during times of peak demand to reduce the risk of outages, or an end user may wish to take control of a utility-owned system during a grid outage to provide local backup power. The study will include:

- Identification of the full range of options for business models (utility ownership, end-user ownership), and their potential pros and cons.
- Outlining the potential role of other funding agencies such as utilities, the California Energy Commission (CEC), and the California Public Utility Commission (CPUC).

Study Area 5: PV Market Penetration Scenarios

Guiding Question: "How much PV could be deployed, when, and where?"
Subordinate Questions:

- *What will be the demand, clearing prices, etc. for PV on a state-by-state basis?*
- *How much PV could we conceivably deploy into the U.S. market, absent barriers?*
- *What are the effects of current barriers on the "ideal" deployment scenario?*

Study Description:
This study will develop a set of potential scenarios for PV market penetration within the US between 2007 and 2015. The expected result of this study is a report that describes the expected levels of annual sales, average selling prices, installed capacity, etc. on a state-by-state basis with high fidelity from 2007-2010 and slightly less fidelity from 2010-2015.

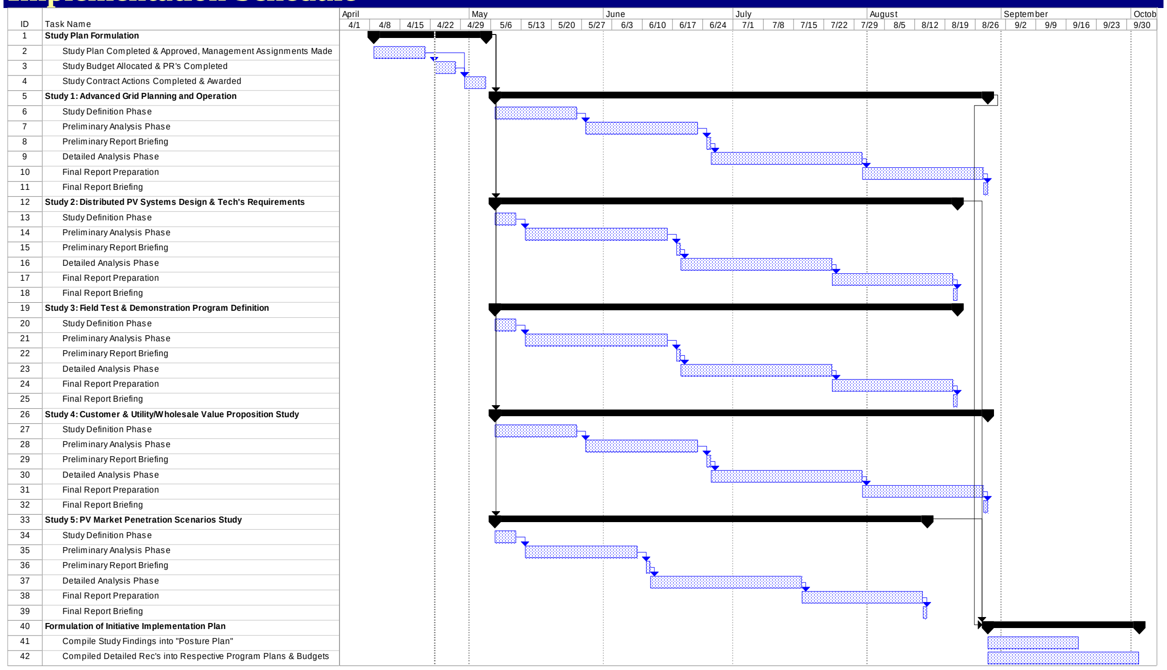
This study will use data collected from industry and other sources to provide inputs for expected manufacturing costs and production volumes. The demand-side data will be derived from various Department of Energy and FERC sources, as well as some other possible sources for calibrating expected price increases for conventional electricity substitutes. The critical data on the demand side would include electricity sales (current and predicted future), utility-provided electricity price points (current and predicted future with price escalations), utility rate structures, electricity demand projections, etc.

The study will be based on investigations using a combination of extant literature and market reports, models such as the NREL SolarDS tool, and new spreadsheet analysis tools. These tools will consider variables/parameters such as those designated below:

Endogenous Variables	Exogenous Variables	Additional Influential Policy Measures
Supply-Side Inputs • Cost • Production Volumes • "Tolerable" Gross Margin by Year	Supply-Side Policy Inputs • Manufacturing Tax Credit, Loan Guarantees, etc.	National-Level • Solar demand-side ITC • CO_2 cap-and-trade, etc.
Demand-Side Inputs • Electricity "substitute" price • Solar resource • Population growth and per capita energy use • Distribution channel ramp	Demand-Side Policy Inputs • Rate structures (energy and demand/capacity) • Net-metering	State-Level • RPS requirements • REC's trading provisions

rate (installer ability to scale up level of installations) • Existing electricity supplies and planned capacity additions • Existing and planned T&D infrastructure	• Interconnection procedures • Rebates • Permitting costs & procedures	

Implementation Schedule

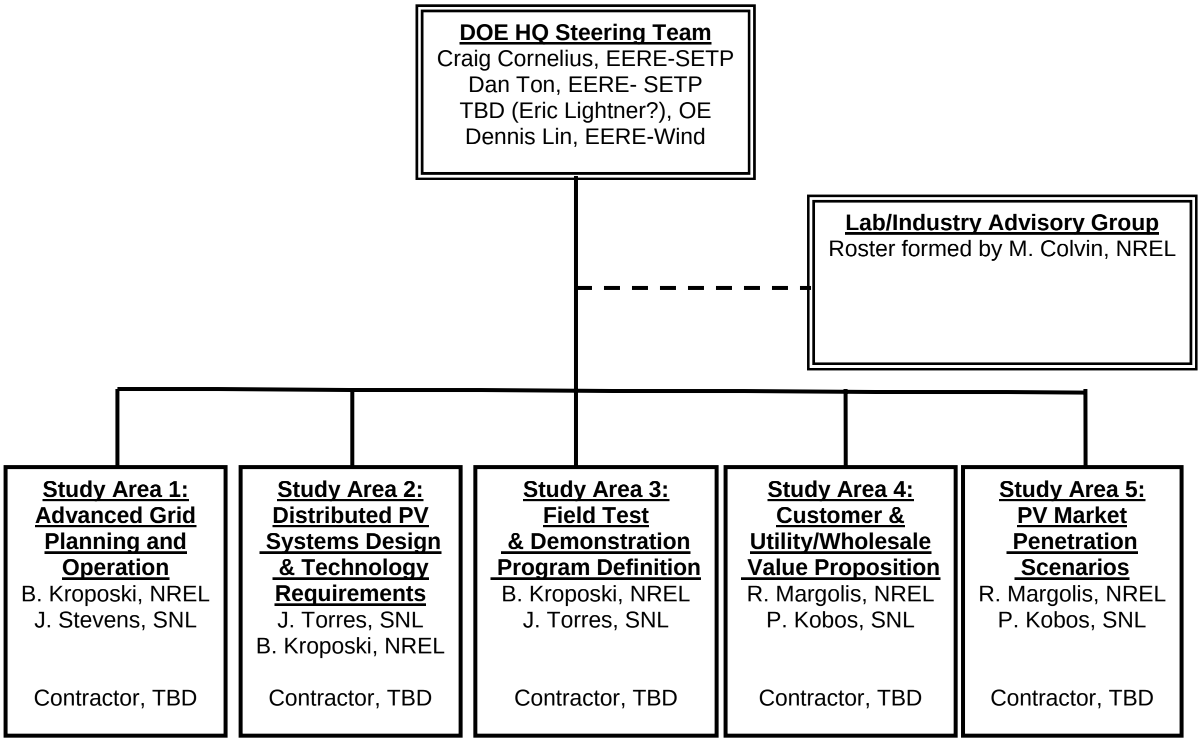


Management Approach

The cooperating program offices from the Office of Electricity Delivery and Reliability (OEDR) and the Office of Energy Efficiency & Renewable Energy (EERE) will appoint a Steering Team of officials from DOE Headquarters to oversee the study effort. With advisory input from a group that will be convened via NREL, this Steering Team will review and guide the implementation of this study plan, which will be lead by co-leads to be appointed out of NREL and Sandia National Laboratories.

For each study area a DOE and Lab lead will be designated. For each study, a contractor study team will be formed through the competitive award of a new contract or, where appropriate, the modification of an existing contract. The lead contractor will be expected to develop an approach that meets the needs of each study, including formation of sub-contractor relationships where data and/or analytical support are required.

This management structure is shown below: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Study Area 5: PV Market Penetration Scenarios
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